THE INTERSTELLAR ABUNDANCE OF NITROGEN


P. L. Dufton, Dept. of Pure and Applied Phys., QUB.

1. Introduction

In a recent paper York et al (1983) have investigated the interstellar abundance of nitrogen from an analysis of interstellar N I absorption lines with small oscillator strengths \( f \leq 2.6 \times 10^{-3} \). The importance of using weak lines in abundance determinations is well known, as they tend to lie on the linear portion of the curve of growth so that the resultant column density of a species depends only on the \( f \)-value of the transition and the equivalent width (see for example Spitzer 1978). Obviously, oscillator strengths therefore need to be determined to a high degree of accuracy. Unfortunately this is not usually the case for the weak lines used in the study of the interstellar medium such as the Mg II 1240A doublet (Hibbert et al 1983). The N I values used by York et al (1983) were generally deduced from the observed curves of growth of other N I lines, a method which can lead to substantial errors as in the case of Si II (see for example Dufton et al 1983).

Hibbert et al (1985) have calculated accurate oscillator strengths for the 951, 952 and 1160A multiplets of N I using sophisticated configuration-interaction wavefunctions, and found them to differ significantly from those employed by York et al (1983). In this paper the Hibbert et al \( f \)-values are used in conjunction with the equivalent widths analysed by York et al to investigate more rigorously the depletion of nitrogen in the interstellar medium.

2. Method of analysis and results

Observed N I equivalent widths \( W(\lambda) \) were principally taken from the survey of Bohlin et al (1983), who observed many UV interstellar absorption lines towards 88 early-type stars with the Princeton high-resolution spectrograph on the Copernicus satellite (Rogerson et al 1973). Additionally, Copernicus data for several stars not observed by Bohlin et al were taken from Lugger et al (1978). To derive N I column densities, observed values of \( \log (W(\lambda)/\lambda) \) vs \( \log f(\lambda) \) were compared with those calculated from theoretical single-component curves of growth, the procedure being similar to that used previously by, for example, Murray et al (1984) and York et al (1983). Single-cloud analyses were considered to be sufficient as one would not expect a significant contribution to the N I equivalent widths from any small secondary interstellar clouds due to the small oscillator strengths of the lines involved. The range of \( b \)-values was limited to 0.3–6 km s\(^{-1}\) as the former is the typical thermal value for cool interstellar clouds (Spitzer 1978), while the latter is the instrumental resolution of the Copernicus satellite (Rogerson et al 1973), and values greater than this would be
Table 1.

Interstellar Nitrogen Abundances

1. Reddened Stars:

<table>
<thead>
<tr>
<th>Star</th>
<th>$\log N(H_{tot})$</th>
<th>$[N/H]$</th>
<th>Star</th>
<th>$\log N(H_{tot})$</th>
<th>$[N/H]$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>21.07</td>
<td>$\geq 7.9$</td>
<td>1</td>
<td>21.20</td>
<td>$\geq 7.9$</td>
</tr>
<tr>
<td>$\beta^1$ Sco</td>
<td>21.14</td>
<td>7.9</td>
<td>$\omega^1$ Sco</td>
<td>21.24</td>
<td>8.0</td>
</tr>
<tr>
<td>$\delta$ Sco</td>
<td>21.16</td>
<td>7.7</td>
<td>$\sigma$ Sco</td>
<td>21.37</td>
<td>$\geq 7.9$</td>
</tr>
</tbody>
</table>

2. Unreddened Bright Stars:

<table>
<thead>
<tr>
<th>Star</th>
<th>$\log N(H_{tot})$</th>
<th>$[N/H]$</th>
<th>Star</th>
<th>$\log N(H_{tot})$</th>
<th>$[N/H]$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha$ Vir</td>
<td>19.00</td>
<td>7.8</td>
<td>$\delta$ Cru</td>
<td>20.04</td>
<td>7.5</td>
</tr>
<tr>
<td>$\beta$ Cen</td>
<td>19.52</td>
<td>7.8</td>
<td>$\gamma$ Cas</td>
<td>20.16</td>
<td>8.0</td>
</tr>
<tr>
<td>$\alpha^1$ Cru</td>
<td>19.85</td>
<td>7.7</td>
<td>$\lambda$ Lep</td>
<td>20.17</td>
<td>7.6</td>
</tr>
<tr>
<td>$\epsilon$ Cen</td>
<td>19.90</td>
<td>7.6</td>
<td>$\delta$ Lup</td>
<td>20.18</td>
<td>7.7</td>
</tr>
<tr>
<td>$\zeta$ Pup</td>
<td>19.99</td>
<td>8.1</td>
<td>$\theta$ Car</td>
<td>20.28</td>
<td>7.6</td>
</tr>
<tr>
<td>$\zeta$ Cen</td>
<td>20.02</td>
<td>7.7</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. Moderately Reddened Bright Stars:

<table>
<thead>
<tr>
<th>Star</th>
<th>$\log N(H_{tot})$</th>
<th>$[N/H]$</th>
<th>Star</th>
<th>$\log N(H_{tot})$</th>
<th>$[N/H]$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\epsilon$ Ori</td>
<td>20.15</td>
<td>8.0</td>
<td>$\kappa$ Ori</td>
<td>20.52</td>
<td>8.0</td>
</tr>
<tr>
<td>$\delta$ Ori</td>
<td>20.23</td>
<td>8.0</td>
<td>$\sigma$ Ori</td>
<td>20.52</td>
<td>$\geq 8.3$</td>
</tr>
<tr>
<td>$\epsilon$ Ori</td>
<td>20.45</td>
<td>8.0</td>
<td>$\lambda$ Ori</td>
<td>20.80</td>
<td>$\geq 8.1$</td>
</tr>
<tr>
<td>$\epsilon$ Per</td>
<td>20.51</td>
<td>8.1</td>
<td>$\phi$ Ori</td>
<td>20.84</td>
<td>$\geq 8.1$</td>
</tr>
</tbody>
</table>
observed as broadening in the line profiles. This upper limit was not critical in any case as for \( b = 6 \) km s\(^{-1}\) the lines were nearly unsaturated so that increasing \( b \) would have little effect on the resultant column densities. When two or more lines were observed in the same multiplet, the range of \( b \)-values was limited to that compatible with their equivalent widths (including their estimated error bars). For single lines the full \( b \)-value range of 0.3 to 6 km s\(^{-1}\) was considered.

In Table 1 the logarithmic nitrogen to hydrogen ratios [N/H] (on the scale \( \log [\text{H}] = 12.0 \)) are summarised along with the total hydrogen column densities \( \log N(\text{H}_{\text{tot}}) = \log [N(\text{HI}) + 2N(\text{H}_2)] \) from Bohlin et al (1978, 1983). Error bars on [N/H] include uncertainties from the \( b \)-values and observational errors. Following the scheme of Bohlin et al (1983) the stars are grouped into three classes depending on their colour excess \( E_{B-V} \), with Class 1 being the reddened stars \( (E_{B-V} > 0.13) \), Class 2 the unreddened bright stars \( (E_{B-V} < 0.04) \) and Class 3 the moderately-reddened bright stars \( (0.04 < E_{B-V} < 0.13) \). The NI multiplets used to determine [N/H] for each stellar class were: Class 1: 1160A; Class 2: 952A; Class 3: 951 and 1160A. Since the ionization potential of nitrogen is approximately 0.94 eV greater than that of hydrogen, N II should make a negligible contribution to the total nitrogen column densities in the cool line-of-sight H I regions. The values of [N/H] in Table 1 should therefore represent the total gas-phase nitrogen abundances in the stellar sightlines.

In Figure 1 the values of [N/H] are plotted against \( \log N(\text{H}_{\text{tot}}) \) for the three classes of stars, where the dashed line corresponds to [N/H] = 7.96 dex, similar to that found by Lambert (1978) for the Sun, and by Dufton et al (1981) for unevolved stars.

![Plot of the logarithmic nitrogen to hydrogen abundances [N/H] (on the scale \( \log [\text{H}] = 12.0 \)) against total hydrogen column densities \( \log N(\text{H}_{\text{tot}}) \) for the sightlines to the programme stars. The dashed line refers to the cosmic abundance value [N/H] = 7.96, and the arrows indicate lower limits.](plot.png)
B-type stars. We note that $N(H_{tot})$ correlates well with $E_{B-V}$ and the mean line-of-sight density $n_H$ (Bohlin et al 1978) so that any statement regarding the variation of [N/H] with $N(H_{tot})$ applies equally well to these other parameters.

3. Discussion

It can be seen from Table 1 that for the reddened and moderately-reddened stars the results are consistent with there being little or no depletion of nitrogen in the lines of sight. However, for the unreddened stars there is a mean depletion of approximately $0.2 \text{~dex}$. This is unexpected, as normally those species found to be depleted in the interstellar medium, such as Fe II (Shull et al 1983), Mg II (Murray 1983) and Ca II (Phillips et al 1984), have depletion increasing with reddening, generally thought to be due to the adhesion of atoms or ions to interstellar grain surfaces in the denser regions (Duley and Millar 1978). How nitrogen could show an opposite trend is unclear, although there are several possibilities. These are discussed separately below:

(a) There may be a systematic error in the equivalent widths of the N I 952A lines. Bohlin et al (1983) note that, as well as their tabulated errors due to Poisson statistics alone, the values of $W(\lambda)$ may be affected by errors in the subtraction of the background which is due to scattered light. However, this is unlikely to affect the equivalent widths by more than a few percent, and is almost certainly much less than the $60\%$ change typically required to remove the depletion for the unreddened stars.

(b) The 952A multiplet oscillator strengths may be approximately $60\%$ too large. However, Hibbert et al (1985) note that these values should be accurate to $10-20\%$ and are certainly in error by less than the amount required.

(c) The material in the lines of sight to the unreddened stars may be actually underabundant in nitrogen with respect to the adopted value. In this context we note that of the nine unreddened stars which show nitrogen depletion, eight lie at galactic longitudes $l=303^\circ \pm 14^\circ$ at distances of typically 150 pc (see Tables 1 and 3 of Bohlin et al 1978 and 1983 respectively). Hence, the lines of sight to these stars may be mainly sampling a common cloud. Additionally, the two unreddened stars with normal [N/H] ratios ($\xi$ Pup and $\gamma$ Cas) are at $l=256^\circ$ and $124^\circ$ respectively, well away from these sightlines. It is therefore possible that the H I material towards the region $l=303^\circ$ may be nitrogen deficient as has been found for the cluster NGC 6231 (Dufton and Lennon 1982, Keenan et al 1984). In such a case the atmospheres of any stars formed from this material would also exhibit a similar nitrogen underabundance. Unfortunately, even young early-type stars have typical main-sequence lifetimes of ten million years (de Loore et al 1978) and, hence, may move an appreciable distance from their point of origin. Therefore it is extremely difficult to identify any stars as being formed in this region.

(d) The values of $N(H_{tot})$ may be overestimated for the unreddened stars. As these objects have small Lyman-$\alpha$ equivalent widths from which $N(H I)$ is determined (see Bohlin et al 1978), there is a strong possibility of contamination by stellar Lyman-$\alpha$ absorption. Hence, the derived H I column densities may be too large which would lead to underestimates for [N/H].
4. Conclusions

The main conclusion of our survey is that nitrogen appears to be undepleted towards moderately-reddened and reddened stars, in contrast to the results of Ferlet (1981) and York et al (1983) who found [N/H] to be approximately 70% and 50% of the cosmic value respectively. However, our result is consistent with the theories of nitrogen formation/adhesion into grains or grain surfaces in the interstellar medium, as these predict that this element should exist predominantly in the gaseous phase (Field 1974, Duley and Millar 1978).

For the unreddened stars, a depletion of 0.2 dex is found, possible causes for this being contamination of the Lyman-\alpha interstellar lines by stellar absorption, systematic errors in the NI equivalent widths or oscillator strengths, or, alternatively, nitrogen-deficient material in the sightlines to these stars.

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References


F. P. Keenan and A. Hibbert
Dept. of Applied Mathematics and Theoretical Physics
The Queen's University of Belfast
Belfast BT7 1NN
Northern Ireland.

P. L. Dufon
Dept. of Pure and Applied Physics
The Queen's University of Belfast
Belfast BT7 1NN
Northern Ireland.